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6. AUTHORS

James L. Merlo, Ricard Gilson, Peter .A. Hancock

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University of Central Florida
Orlando, FL 32826 -0150

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14. ABSTRACT

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Crossmodal Congruency Benefits for Tactile and Visual Signaling

James L. Merlo, Richard Gilson and P. A. Hancock

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CROSSMODAL CONGRUENCY BENEFITS FOR TACTILE AND VISUAL SIGNALING

James L. Merlo
United States Military Academy
West Point, NY 10996

Richard Gilson
University of Central Florida
Orlando, FL 32826

P. A. Hancock
University of Central Florida
Orlando, FL 32826

An experiment is reported in which tactile messages were created based on five common military arm and hand signals. We compared response times and accuracy rates of novice individuals responding to visual and tactile representations of these messages. Such messages were displayed either alone or in congruent or incongruent combinations. Analyses were conducted on trials where tactile and visual signals messages were presented either individually or concurrently. Results indicated a beneficial effect for congruent message presentations with both modalities showing a superior, combined response time and improved accuracy when compared to individual presentations in either modality alone. These results confirm the promise for tactile messages to augment visual displays in challenging and stressful environments where visual messaging may not always be clear or even possible.

Introduction

Many operational conditions such as combat, fire fighting, or certain law enforcement and/or emergency management situations impose significant demands on operator's sensory capabilities. Noisy (e.g., weapons fire, vehicle engines, etc.) and murky (e.g., smoke, sandstorms) environments, for example, impose great demands on hearing and vision, and can compromise the ability to exchange critical information through conventional communication pathways (Merlo, Szalma, & Hancock, 2007). To circumvent these environmental barriers it may be possible to provide a redundant source of information through the modality of touch, by using tactile signaling.

Previous studies have shown tactile systems can produce relatively stable performance improvements across a variety of body orientations even when spatial translation is required (Oron-Gilad, Downs, Gilson, & Hancock, 2007; Terrence, Brill, & Gilson, 2005) as well as in the presence of physiological stress (Merlo, Stafford, Gilson, & Hancock, 2006). Comprehensive review of these and other tactile studies have recently appeared (see, Gilson, Redden, & Elliot, 2007; Prewett, Yang, Stilson, Gray, Coovert, & Burke, 2006).

Most of human information processing uses multiple sensory inputs, primarily involving the synthesis of visual and auditory cues (Hancock, 2005; Spence & Driver, 2004; Stein & Meredith, 1993). Literature on experiments that involve the use of two modalities of information presented redundantly, namely tactile and visual, each show improvement in the areas of accuracy and response time (Spence & Walton, 2005; Gray & Tan, 2002; Strybel & Vatakis, 2004). The present study seeks to show that similar congruency benefits may be achieved for more complex stimuli presented through both the visual and tactile modalities.

Experimental Method

Experimental Participants

To investigate the foregoing proposition, twenty participants (9 males and 11 females) ranging in age from 18 to 48, with an average age of 25 years, volunteered to participate. Each participant self-reported no surgeries, significant scarring or any impediment that might cause lack of feeling in the abdomen or torso area. None of the participants had any prior experience with the presented arm and hand signals nor the tactile signals in general, beyond the possible familiarity with cell-phone vibratory alerts.

Experimental Materials and Apparatus

The vibrotactile actuators (tactors) in our system are model C2, manufactured by Engineering Acoustics, Inc. They are acoustic transducers that displace 200-300 Hz sinusoidal vibrations onto the skin. Their 17 gm mass is sufficient for activating the skin's tactile receptors. The C2's contactor is 7 mm, with a 1 mm gap separating it from the tactor aluminum housing. The C2 is a tuned device, meaning it operates well only within a very restricted frequency range, in this case approximately 250 Hz. The tactile display itself is a belt like device with eight vibrotactile actuators, an example of which is shown in Figure 1. The belt itself is made of elastic and high quality cloth similar to the material used by professional cyclists. When stretched around the body and fastened, the wearer has an actuator over the umbilicus and one centered over his spine in the back.

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The other six actuators are equally spaced, three on each side, for a total of eight (see Cholewiak, Brill, & Schwab, 2004).

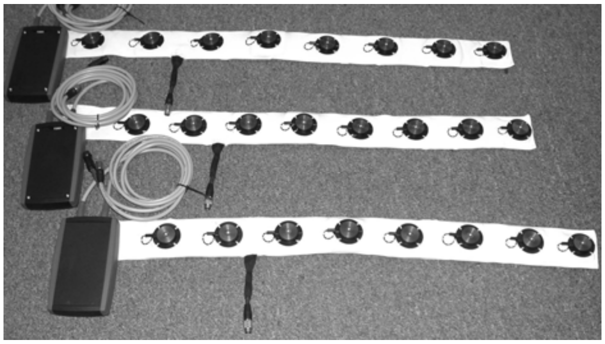

Figure 1. Three tactile displays belt assemblies are shown above along with their controller box.

The tactors are operated using a Tactor Control Unit (TCU) which is a computer-controlled driver/amplifier system that switches each tactor on and off as required. This device is shown on the left side of the tactile displays belts in Figure 1. The TCU weighs 1.2 lbs independent of its power source and is approximately one inch thick. This device connects to a power source with one cable and to the display belt with the other and uses Bluetooth technology to communicate with the computer driven interface. Tactile messages were created using five standard Army and Marine Corps arm and hand signals (Department of the Army, 1987). The five signals chosen for the experiment were, “Attention”, “Halt”, “Rally”, “Move Out”, and “Nuclear Biological Chemical event (NBC)”. The tactile representations of these signals were designed in a collaborative effort of scientists at the University of Central Florida and a consultant group of subject matter experts (SMEs) consisting of former US Soldiers and Marines.

Short video clips of a soldier performing the five arm and hand signals were edited to create the visual stimuli. Careful editing ensured the timing of the arm and hand signals closely matched that of the tactile presentations (see Figure 2). A Samsung Q1 Ultra Mobile computer using an Intel Celeron M ULV (900 MHz) processor with a 7” WVGA (800 x 480) liquid crystal display was used to present videos of the soldier performing the arm and hand signals. This computer ran a custom LabVIEW (8.2; National Instruments) application that presented the tactile signals via Bluetooth to the tactor controller board and captured all of the participant’s responses via mouse input. Participants wore sound dampening headphones with a reduction rating of 11.3 dB at 250 Hz to reduce the effects of any auditory stimuli emanated by the tactor actuation.

The display of each message or signal was presented in one of four ways:

- visual only (video presentation of the arm and hand signal)
- tactile only (tactile presentation of the arm and hand signal)
- both visual and tactile simultaneous and congruent (i.e. the same signals were presented both through the video and through the tactile system)
- Both visual and tactile simultaneous and incongruent (i.e. the visually presented signal did not match the presented tactile signal)

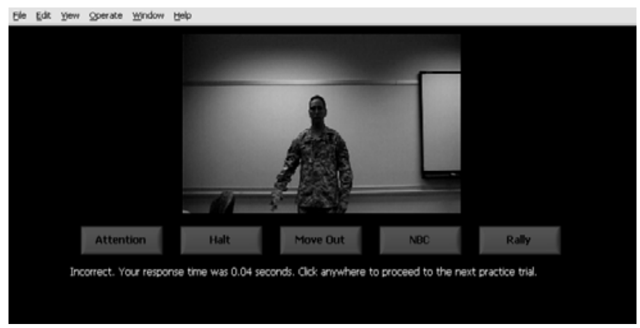

Figure 2. A computer screen shot showing what the participant viewed as the signals were presented. The participant mouse clicked on the appropriate signal name after each presentation.

Experimental Design and Procedure

Participants first completed a computer-based tutorial that described each arm and hand signal individually. For each signal, a short description was presented. Participants then viewed a video of a soldier performing the signal followed by the experience of its tactile equivalent. Finally, the participants were able to play the signals concurrently (both visual and tactile representation at the same time). Participants were allowed to repeat the presentation (i.e., visual, tactile, visual-tactile) as many times as desired. Once the participant reviewed the five signals in the two presentation styles, a validation exercise was performed. Participants had to correctly identify each signal twice before the computer would prompt the experimenter that the participant was ready to begin.

Each participant performed two, sixty trial blocks. The blocks had two of each signal presented only visually (10 total), two of each signal with only tactile signals (10 total), four of each signal performed simultaneously with both congruent visual and tactile presentation (20) and four of each tactile and visual signal performed simultaneously but as incongruent presentations (20). Each participant performed two blocks of trials, with the sixty trials within the blocks completely randomized for each participant. For any one indivisual participant, the entire procedure took less than an hour to complete.

Results

All analyses reported were conducted using SPSS 11.5 for Windows with the alpha level set at .05 for a two-tailed *t-test* conducted unless otherwise noted. Results were analyzed in terms of the speed of response and the accuracy of that response under the respective conditions. Only the results from the three conditions of visual presentation, tactile presentation and congruent, concurrent presentation are presented in the present paper.

A one-way Analysis of Variance (ANOVA) was performed on the mean response times across the three experimental conditions of visual presentation, tactile presentation or visual-tactile concurrent and congruent presentation, with the following result: $F(1, 19)=473.45$, $p<.01$, (η^2_p = .961, β= 1.00).

Subsequent *a priori* pairwise analysis showed, simultaneously presented congruent signals resulted in significantly faster response times than visual signals presented alone $t(19)=-2.25$, $p\leq.04$, see Figure 3 below. Also, as is evident, the congruent signals were faster than tactile alone $t(19)=-3.98$, $p\leq.01$. Additionally, the visual only presentation of the signal was significantly faster than the tactile only presentation of the signal t(19)=-2.16, $p\leq.04$.

Although, there was no traditional level of significant difference in accuracy rates observed between the visual and tactile signals when presented alone $t(19)=2.00$, $p\leq.06$, there was a significant difference in the performance rates when the tactile modality was compared to the concurrent congruent presentation of the signals, $t(19)=4.03$, $p\leq.01$. The overall lower accuracy rate for the tactile signaling was due to an apparent confusion between the tactile signal for 'NBC" and 'Halt", which have similar tactile characteristics but comparatively low visual similarity. Analysis without the "NBC" tactile signal data removed these differences (it was not significantly different with it included) in the error rate between visual and tactile signals, while not influencing the main effect between congruent modality signaling and single modality signaling at all.

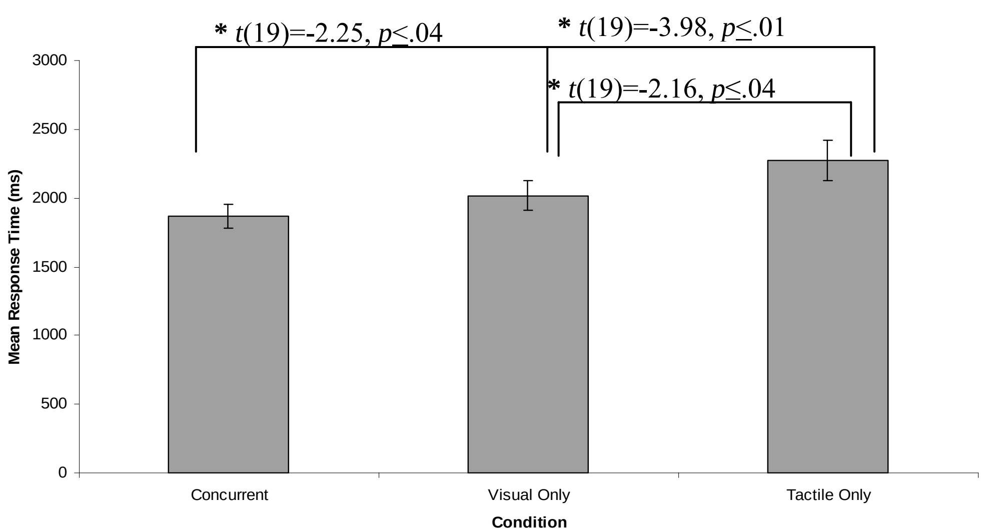

Figure 3. Response time in milliseconds by signal presentation condition.

Discussion

The overall high accuracy rate displayed by the participants (over 80% across all modalities with fewer than ten minutes of training) is highly encouraging to the current form of tactile display. The accuracy of the messages and the reported intuitiveness with which they were received is also a testament to the utility of the subject matter expert information and the present tactile 'language' transformation format. Similarities in both tactile and visual signals that cause confusion among signals are virtually eliminated in concurrent presentation. The rich multi-modal information format seemed to produce faster and more accurate performance.

The question of learning complex tactile communication signals, especially for use in adverse or unusual circumstances is liable to be an important future issue. The tactile system acts as a redundancy gain as the participants now have two means of receiving communication because the visual hand and arm signals would still be available. While initial testing seems to result in superior performance for tactile communication and traditional arm and hand signals combined, the challenge of a universal input device remains a significant hurdle. Stimulus response compatibility will have to be analyzed carefully to maximize performance as different types of inputs are considered for use with tactile displays. However, when individuals are faced with extreme challenges and the traditional sources of information are either diminished of eliminated altogether, the tactile system provides an important alternative communication channel and one that can and should be exploited.

Up until the present innovative development in tactor technology , the results for tactile signaling alone, or in combination with other modalities, has been rather mixed. Now that clear and unequivocal messages can be supplied to various body locations including most interestingly, the tongue, the opportunity to exploit this relatively unexploited sensory channel presents itself. However, beyond the practical and pragmatic issues of display generation, these issues of multi-sensory signaling pose critical theoretical challenges as to the temporal sequencing of stimulation across the information processing system. We will have to know much more about the buffering and prioritizations of multiple competing cues in order to avoid confusing or contradictory communications. We will have to explore the nature of the primacy of "direct" versus "interpretive" tactile signals and especially what connotes "intuitively obvious" signals in this realm. Although these represent significant challenges, these early results suggest that the practical benefits alone which can accrue will be worth the effort.

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